

## **Progress Report: NOAA GAPP**

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### **The Effects of Orography on the Cold-season Hydrometeorology in California**

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**Period of performance: July 2004 – January 2005**

## **OVERVIEW**

The study aims at understanding the role of mesoscale terrain, in particular the Coastal Range and the Sierra Nevada, in shaping the cold season climate and water cycle in California using a regional climate model (RCM) and observations. The knowledge gained from this study will provide valuable insights in the water cycle in California and how they are affected by the variations in the large-scale circulation and the anticipated global climate change induced by the increases in the atmospheric greenhouse gases that are among the primary concerns in extended-range forecasting and climate change impact assessments for the region.

The main research plan for the second-year are:

- (1) Complete seasonal simulations and evaluate the results against observations.
- (2) Perform case studies for selected storm events and analyze the results.
- (3) Obtain the observed low-level wind and precipitable water vapor (PWV) data from the NOAA/ETL and the NADA/JPL for selected cases.
- (4) Submit a paper from seasonal simulations.
- (5) Submit the second-year project report.

In the report period, two seasonal RCM runs have been completed for the winters of 1997-1998 and 1998-1999. Another seasonal simulation for investigating the role of the mesoscale orography in the southern Sierra Nevada region in shaping the impact of direct atmospheric aerosol forcing on surface insolation and snow budget in the spring of 1998 has been performed. In addition, a number of short case studies have been performed for cold- and warm storm cases identified by the NOAA-ETL collaborators. The PWV data from the Southern California GPS Network (SCIGN) also have been obtained from the NASA/JPL collaborators. The GPS-PWV data have been subsequently used in a case study in conjunction with the operational NCEP Eta model initial fields to investigate whether the local GPS network can improve quantitative precipitation simulations in the southern California region.

## OUTLINE OF THE PROGRESS DURING THE REPORT PERIOD: July 2004 - January 2005

### *1. Cold-season hydroclimate simulations*

Six-month seasonal simulations, October through March, have been performed for the two contrasting winters of 1997-1998 and 1998-1999 over an 18-km resolution California domain (Fig. 1) using the MAS model. The domain includes California and Nevada with a buffer area for implementing large-scale forcing along the lateral boundaries. At this spatial resolution, the model terrain well represents the orography of the northern Coastal Range and the Sierra Nevada that strongly affect the cold season low-level moisture fluxes. In addition, a number of short-term simulations have been performed for the cold and warm storm periods identified in Nieman et al. (2002) for detailed investigation of the low-level flows under two different large-scale environments. For these short-term airflow analysis runs, a Lagrangian tracer model has been incorporated into the MAS. As discussed in the Year-1 report, the large scale data from ECMWF and R2 yielded notable differences in the simulated precipitation. Without means to determine which forcing is more accurate, R2 data are used in the rest of the experiment.

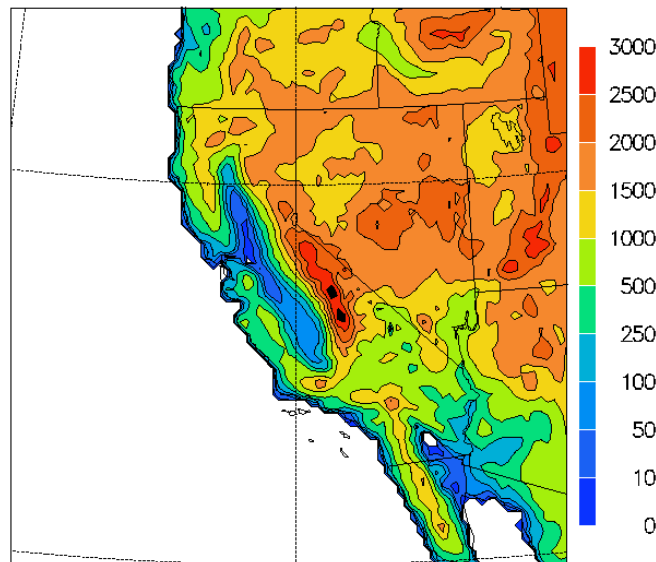


Figure 1. The domain and model terrain elevations of the CA18 domain.

The seasonal runs simulated well precipitation differences between the two contrasting winters (Fig. 2) which are characterized by warm-wet (1997-1998) and cold-dry (1998-1999) conditions. The simulations (Fig. 2a) show much larger precipitation differences in the northern California Coastal Range and the northern Sierra Nevada (southern Coastal Range) during January (February) in the El Nino winter of 1997-1998. The two seasonal runs also show clearly the drier conditions in the early part (October-December) of the 1997-1998 winter compared to the 1998-1999 winter. Overestimation of precipitation in the Coastal Range and the Sierra Nevada regions may be partially due to the fact that local precipitation maxima in mountainous regions are significantly underestimated in the URD analyses as reported in the Year-1 progress report.

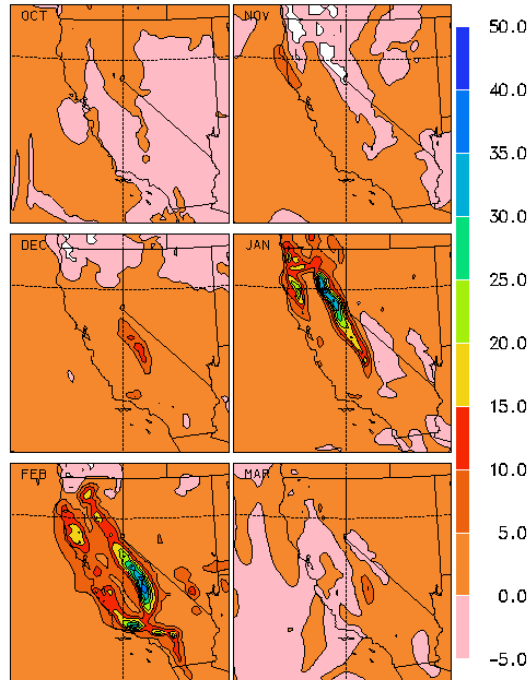


Figure 2a. The monthly precipitation differences (mm day<sup>-1</sup>) between the winters of 1997-1998 and 1998-1999 (97w-98w) from the seasonal simulations.

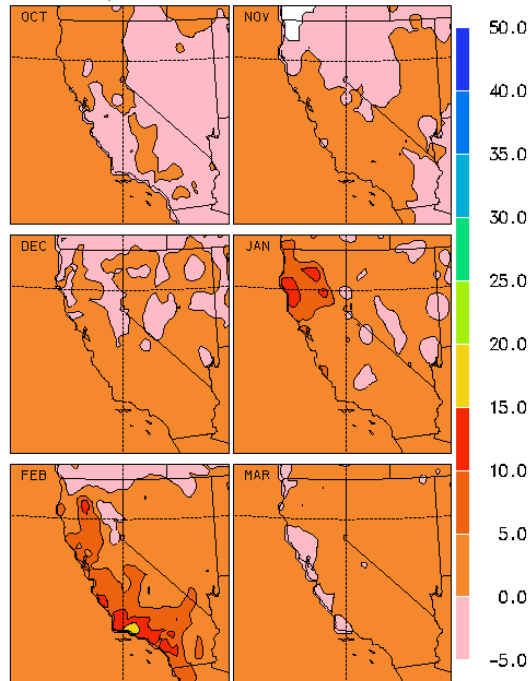


Figure 2b. Same as Figure 2a, but from the NCEP-URD (97w-98w). Note that the URD data cover only land surfaces.

Additional evaluation of the simulated precipitation is underway using station data which represent local precipitation maxima more accurately than the URD data. Based on these evaluations, analyses of the low-level winds, daily precipitation and land surface fields in the simulations are being performed.

## 2. Elevation dependence of the effect of direct aerosol radiative forcing on surface insolation and spring snowmelt

The role of aerosol radiative forcing in shaping regional energy and water cycles is an important concern in projecting the impact of climate change on water cycle, but it remains largely uncertain. The impact of aerosol radiative forcing on spring snowmelt in the Sierra Nevada basins is a particular concern in California as the amount and timing of snowmelt and snowmelt-driven runoff in these high elevation basins are crucial for the warm season water supply in California. The impact of aerosol radiative forcing on snow cover in turn affects regional energy budget via altering surface albedo. Significant elevation variations in the Sierra Nevada region that ranges from the sea level to over 3000 m may play an important role in determining the response of snow field to the changes in the surface insolation due to aerosols. As shown in Kim (2001), the large temperature changes associated with extreme elevation variations in the Sierra Nevada region causes the surface water cycle to respond to the changes in the large-scale forcing in a very complex way. In addition, cloud formations due to orographic lifting tend to be more frequent in higher elevation regions and will further complicate the net impact of aerosol radiative forcing on the surface water cycle.

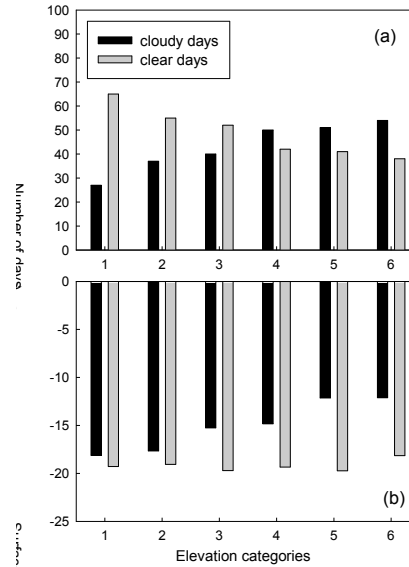


Figure 3. The (a) number of cloudy and clear days and (b) direct aerosol radiative forcing on surface insolation averaged over cloudy (black) and clear (gray) days in each elevation band. The elevation category (EC) 1 covers from the sea level to 1 km. The ECs 2-6 cover the elevation ranges:  $1000 + 500 \times (EC - 1) < z < 1000 + 500 \times EC$ .

To examine the impact of aerosol radiative forcing on surface insolation and snowmelt in spring, a seasonal simulation has been performed over the CA18 domain (Fig. 1) for the 3-month period March-May 1998 using the most recent MAS model that includes the Fu-Liou  $\delta/4$ -stream radiation scheme with aerosol optical properties. The results from this study show that the impact of aerosols on surface insolation tends to be smaller in higher elevation regions as the influence of cloud cover increases with increasing elevation (Fig. 3). This result also shows that clouds can effectively mask a large portion of the direct

aerosol radiative forcing on surface insolation, and, for a quantitative assessment, indirect aerosol radiative forcing must be included in the simulation.

The insolation changes due to aerosol radiative forcing affect snowmelt only in high elevation regions above the 2000 m level. A further examination of the reduction in snowmelt, the change in surface insolation, and the low-level temperature due to direct aerosol radiative forcing reveals that snowmelt changes are more closely related to the low-level temperature than changes in surface insolation (Fig. 4). The largest change in snowmelt occurs when the low-level temperature is between  $-3^{\circ}\text{C}$  and  $5^{\circ}\text{C}$ . This is due to the fact that snowmelt occurs when the low-level air temperature is near  $0^{\circ}\text{C}$ . If the low-level air temperatures are too high, snowmelt is dominated by the warm air and the aerosol radiative forcing effect becomes negligible. On the other hand, cold low-level air temperatures prohibit snowmelt. In this situation, the aerosol radiative forcing effect on snowmelt becomes small as well.

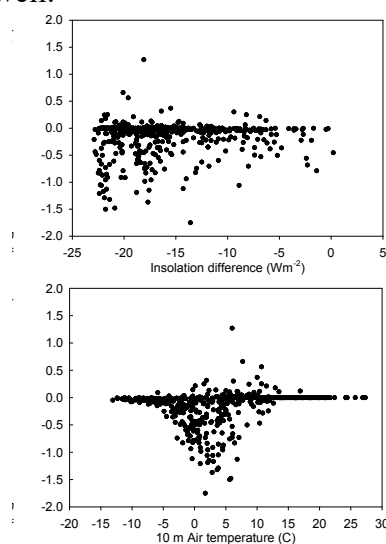


Figure 4. The relationship between the snowmelt differences and (top) the magnitude of surface insolation and (bottom) low-level air temperature.

### ***3. Airflows during the cold and warm storms: case studies***

To examine the low-level mesoscale flows affected by the Coastal Range and the Sierra Nevada and the associated low-level water vapor transports, a Lagrangian particle tracer model was implemented into the MAS model. The model was employed in simulating wind fields during two storm period characterized by a warm-sector (Fig. 5a) and a cold-sector (Fig. 5b) environment. Comparison of Fig. 5a and 5b shows that the wind fields below the mountain-top level are affected significantly by the low-level temperature variations. During the warm storm period (Fig. 5a), the wind fields in the lowest two model layers that are below the Coastal Range tend to maintain its upstream direction until they hit the Sierra Nevada which is much higher than the Coastal Range. During the warm storm period, the tracers released in the lowest two model layers are transported northwestward suggesting that the winds below the Coastal Range are strongly affected by the orography. These differences in the low-level winds between the two northern

California storm cases are similar to the results by Nieman et al. (2002) from their wind profiler studies during a CALJET campaign.

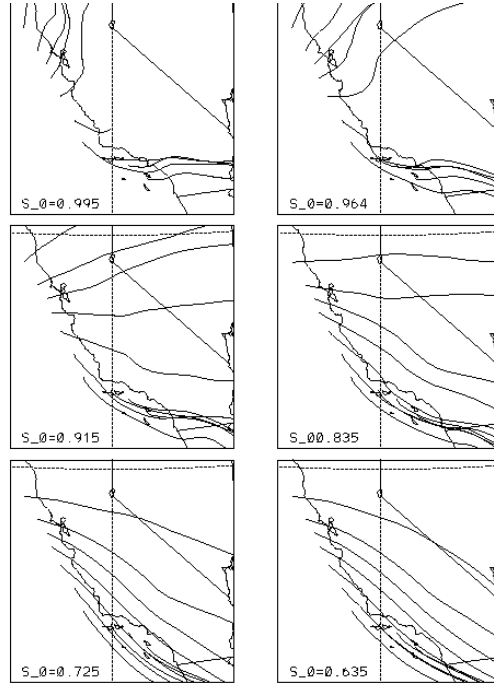


Figure 5a. Particle trajectories over the 24-hr period from 12UTC 11 January 1998 during a warm storm event. The particles were released at  $\sigma=0.995$ ,  $0.964$ ,  $0.915$ ,  $0.835$ ,  $0.725$ , and  $0.635$  at 10 different positions along the California coastal line.

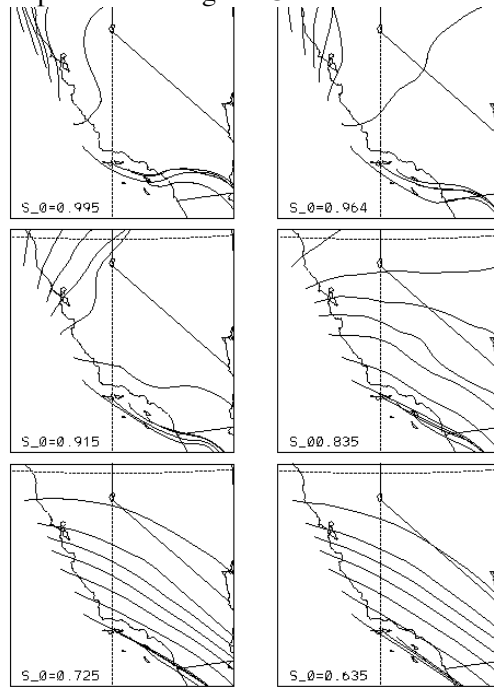


Figure 5b. Same as Figure 5a, but over the 24-hr period from 12UTC 14 January 1998 during a cold storm period.

Based on this case study, a fine-resolution experiment for resolving orographic wind fields is being designed. The most difficult part of this study comes from that objective definitions of cold and warm storm environments are not available. As a part of the third year research plan, the PI will attempt to find if the deflection of the low-level winds is related to the local Froude number defined as  $Fr = U / Nh$ . Water budget will also be calculated at hourly intervals across the two mountain ranges to quantify the contributions from advection, evaporation and precipitation.

#### ***4. Research Plan for the Third Year***

The research plan during the third year aims at completing the case studies and analyses of the simulated low-level wind fields and the associated water vapor transport. For a more detailed investigation of the orographic blocking, fine resolution simulations will be performed for three sets of cold/warm storm cases in the northern, central and southern California regions that have been identified in the observational study by Nieman et al. (2002). Water budgets across the two California mountain ranges will be investigated to estimate the amount of water vapor transport associated with barrier jets under warm and cold storm cases. The effects of terrain elevations on the surface water cycle, especially on the partitioning of rainfall and snowfall and snow budget, during the cold and warm events will be investigated from the simulations. The results will be reported in the final report as well as in papers.

#### ***5. Publications and Presentations Supported by the Project***

- Kim, J., Y. Gu and K.-N. Liou, 2004: Elevation dependence of the direct aerosol radiative forcing on surface insolation and spring snowmelt in the southern Sierra Nevada. *Geophys. Res. Lett.*, submitted.
- Kim, J., Y. Gu and K.-N. Liou, 2004: The effects of the direct aerosol radiative forcing on spring snowmelt in the southern Sierra Nevada: Elevation dependence. 2004 GAPP PI meeting, 30-31 August, Boulder, CO.